South Dakota
SURVEY REPORT

Compilation of Elk Survey Methods and Results Reports

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INTRODUCTION

Population management objectives are established across 18 antlerless elk (*Cervus elaphus*) harvest management units in South Dakota. The South Dakota Game, Fish and Parks (SDGFP) Commission sets biennial elk hunting license allocation and season structure, and these are used as the primary management option to meet population objective goals. Estimates of the elk population and antlerless harvest are used to inform management across 11 antlerless elk management units within the Black Hills management area. Age- and sex-ratio data from pre-hunting season herd composition surveys provide 2 valuable sources of information about the elk population. Specifically, age-ratios, calf:100 adult cow elk, are used to estimate annual recruitment rates, and sex-ratios, adult bull:100 adult cow elk, are used to estimate adult cow and adult bull cohorts from late-winter abundance surveys conducted every 4 years in the Black Hills. Both sources of data are integral for projecting future elk populations from late-winter aerial abundance surveys.

METHODS

Pre-hunting season herd composition surveys are completed by driving roads or hiking in areas of known elk concentrations in August. Surveys are concentrated in locations across the Black Hills according to where elk are distributed and can be observed. Although there is no statistical survey design, survey efforts are designed to provide efficient data collection while still representing the Black Hills elk population. In addition to late-winter aerial observation surveys, location data from harvested elk and SDGFP staff familiarity of elk distribution before the hunting season helps facilitate representation of the survey. All elk herds that are observed in their entirety are classified to numbers of calves, adult cows, and adult bulls. Location and date of observations are also recorded to reduce double-counting occurrences.

Sex ratios calculated from these counts may under-represent branch-antlered bulls because large calf and cow groups, common in August, likely have a higher detection probability than adult bulls in smaller groups. Elk survey protocol during previous years allowed surveys to be completed in both August and September, and higher bull to cow ratios were observed in September. Because bull groups generally integrate into cow and calf groups during the breeding season, which begins in September, detection probability is thought to be more similar for all cohorts during September. Although it is assumed adult bulls are under-represented in the August survey, as a courtesy to elk hunters in September, SDGFP does not conduct surveys that may disrupt elk movement in September during the hunting season. The hypothesized under-estimate of bulls will result in a biased high growth rate from harvest-

based population projection models. However, the consistency in the monitoring design and recurrent, 4-year abundance surveys allows models to be calibrated to account for potentially overestimated growth rates.

Model Structure

The multinomial distribution is used to model the proportion (π) of observations within each of the 3 cohorts (*k*); calves, adult cows, and adult bulls.

$$\pi_k = \left[\frac{exp(\eta_k)}{\sum_{k=1}^{K} exp(\eta_k)}\right]$$

Age- and sex- ratios are then calculated from the proportions. For example, the calves:100 adult cow ratio can be calculated by dividing the proportion of calves by the proportion of adult cows and multiplying by 100. The sampling unit is treated as each individual elk. Markov Chain Monte Carlo iterations are used to fit models in Program R and estimate age- and sex- ratios with associated standard errors and 95% credible intervals (Plummer 2003, R Development Core Team 2016, Su and Yajima 2015).

RESULTS

The 3-year average of adult bulls:100 adult cows was 25 in the Black Hills and 28 in Custer State Park (CSP). The 3-year average of calves:100 adult cows was 45 in the Black Hills and 40 in CSP. Historic herd composition data and estimates are included in appendix 1.

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APPENDIX 1

Black Hills and Custer State Park (CSP) fall herd composition observation survey data and results, 2003-2021.

						Bulls:100 Cows		Calves:100 Cows	
Area	Year	Bulls	Cows	Calves	Groups	Mean	SD	Mean	SD
Black Hills	2003	77	416	211	45	18.5	2.3	50.7	4.3
Black Hills	2004	140	454	222	46	30.8	3	48.9	4
Black Hills	2005	104	288	137	27	36.1	4.2	47.6	5
Black Hills	2006	30	129	63	6	23.3	4.8	48.8	7.6
Black Hills	2007	NA	NA	NA	NA	NA	NA	NA	NA
Black Hills	2008	103	179	79	26	57.5	7.2	44.1	6
Black Hills	2009	165	685	358	58	24.1	2.1	52.3	3.4
Black Hills	2010	201	596	282	56	33.7	2.8	47.3	3.4
Black Hills	2011	144	646	340	55	22.3	2.1	52.6	3.5
Black Hills	2012	209	718	356	62	29.1	2.3	49.6	3.2
Black Hills	2013	190	636	305	72	29.9	2.5	48	3.3
Black Hills	2014	116	531	250	59	21.8	2.2	47.1	3.6
Black Hills	2015	153	412	219	44	37.1	3.5	53.2	4.5
Black Hills	2016	191	981	450	43	19.5	1.5	45.9	2.6
Black Hills	2017	229	878	404	58	26.1	1.9	46	2.8
Black Hills	2018	157	580	219	61	27.1	2.4	37.8	3
Black Hills	2019	224	799	340	85	28	2.1	42.6	2.8
Black Hills	2020	195	895	412	48	21.8	1.7	46	2.7
Black Hills	2021	218	901	414	53	24.2	1.8	45.9	2.7
CSP	2003	200	628	232	NA	31.8	2.6	36.9	2.8
CSP	2004	167	479	143	NA	34.9	3.2	29.9	2.9
CSP	2005	98	285	95	NA	34.4	4	33.3	4
CSP	2006	53	106	44	NA	50	8.5	41.5	7.5
CSP	2007	197	307	63	NA	64.2	5.9	20.5	2.9
CSP	2008	92	157	26	NA	58.6	7.8	16.6	3.5
CSP	2009	81	283	54	NA	28.6	3.6	19.1	2.9
CSP	2010	68	71	11	NA	95.8	16.8	15.5	5.1
CSP	2011	38	88	11	NA	43.2	8.6	12.5	4.1
CSP	2012	4	38	13	3	10.5	5.8	34.2	11.5
CSP	2013	10	73	21	5	13.7	4.7	28.8	7.3
CSP	2014	46	220	66	12	20.9	3.4	30	4.2
CSP	2015	48	205	64	15	23.4	3.8	31.2	4.5
CSP	2016	37	199	91	14	18.6	3.4	45.7	5.8
CSP	2017	52	200	115	8	26	4.1	57.5	6.8
CSP	2018	45	148	63	4	30.4	5.2	42.6	6.5
CSP	2019	34	123	31	6	27.6	5.4	25.2	5.1
CSP	2020	52	239	118	10	21.8	3.4	49.4	5.6
CSP	2021	99	288	108	8	34.4	4	37.5	4.3

ESTIMATING ELK SURVIVAL AND CAUSE-SPECIFIC MORTALITY RATES

INTRODUCTION

Population management objectives are established across 18 antlerless elk (*Cervus elaphus*) harvest management units in South Dakota. The South Dakota Game, Fish and Parks (SDGFP) Commission sets biennial elk hunting license allocation and season structure, and these are used as the primary management option to meet population objective goals. Estimates of the elk population and antlerless harvest are used to inform management across 11 antlerless elk management units within the Black Hills management area. Annual survival and cause-specific mortality estimates provide valuable sources of information about the elk population. Specifically, survival from March to September is used to estimate the pre-hunting season adult elk population from late-winter abundance surveys conducted every 4 years in the Black Hills. In addition, annual survival rates are used to project future elk populations to evaluate the effect of various hunting season recommendations. Finally, intermittent monitoring of adult female or calf survival rates can alert managers when survival substantially deviates from normal ranges (e.g., severe winter resulting in significant starvation) and provide a means for proactive management to mitigate erratic changes in elk abundance.

METHODS

Within the Black Hills, adult cows are captured via helicopter dart gunning and chemically immobilized using a combination of butorphanol, azaperone, and medetomidine (BAM; ZooPharm, Laramie, WY). Immobilized animals were traditionally monitored with VHF radiocollars, and since 2020 all elk have been fitted with GPS collars to provide additional data on elk movements and habitat use. In addition, historic data were collected from adult elk and newborn elk calves that were captured shortly after birth and monitored for up to 2 years using VHF radiocollars (Appendix 1).

Monitoring alive or dead status for elk captured as adults occurred within 12-16 days post-capture and all mortalities (<16 days post capture) were labeled as capture-related mortalities, except for vehicle mortalities. Monitoring for all VHF collared elk then occurred one time each month. GPS collared elk were continuously monitored for movement and multiple locations were estimated each day (1 location every 7 hours). All mortalities were investigated to verify death of the animal via physical evidence. In most cases, cause-specific mortality was not identifiable except for vehicle collisions and hunter harvest. Hunter harvest is an important metric used in population modeling and collar reporting by hunters is a vital step in obtaining the most accurate data possible.

Model Structure

Survival rates were calculated from time-to-event data using a hierarchical piecewise constant hazard (Λ) model, smoothed among monthly intervals (Walsh et al. 2018). The multinomial distribution partitioned hazards to estimate cause-specific mortality rates that were used in population projection models.

The likelihood for the cause-specific mortality model was the joint probability that a subject (*i*) was alive through interval *u* – 1, died during interval *u*, and the cause of death was assigned to the k^{th} source of mortality:

$$Pr(t < T_i < t + \Delta, K = k | T_i > t) = \psi_{i,k,u} = exp\left(-\sum_{u=1}^{u-1} \Lambda_{i,u}\right) \times \left[1 - exp\left(\Lambda_{i,u}\right)\right] \times \pi_{i,u,k},$$

where

$$\pi_{u,k} = \left[\frac{exp(\eta_{u,k})}{\sum_{k=1}^{K} exp(\eta_{u,k})}\right],$$

and: $ln(\Lambda_u) = \gamma_u + \beta_{j,u} x_{i,j,u}$, where γ_u represents the baseline log cumulative hazard for the u^{th} interval, $x_{i,j,u}$ = the j^{th} covariate for the i^{th} subject during the u^{th} interval, and $\beta_{j,u}$ = is the effect of the j^{th} covariate during the u^{th} interval and is the log hazard ratio.

Log cumulative hazards and multinomial probabilities were smoothed among monthly intervals. An example of the regularization structure for the intercept of the log cumulative hazard, $\gamma_{0,u}$, was: $\gamma_{0,u} \sim N\left(\gamma_0, \sigma^2\right)$ where $\gamma_0 \sim N\left(0{,}100^2\right)$ and $\sigma \sim Uniform(0{,}10)$.

Markov Chain Monte Carlo iterations were used to fit models in Program R and estimate cause-specific mortality rates with associated standard errors and 95% credible intervals (Plummer 2003, R Development Core Team 2016, Su and Yajima 2015).

RESULTS

In 2021, 114 adult cows were monitored approximately once monthly to assess annual survival rates and cause-specific mortality. Annual survival and cause-specific mortality estimates are provided in appendix 1 and appendix 2.

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APPENDIX 1

Black Hills and Custer State Park (CSP) annual survival rates, 2007-2013 (Schmitz 2011, Simpson 2015, SDGFP 2015, SDGFP 2021).

Year	Area	Sexes	Ages	Mean	SD	# Monitored
2007	Black Hills	Female	Adult	0.56	0.06	39
2008	Black Hills	Female	Adult	0.68	0.06	41
2009	Black Hills	Female	Adult	0.62	0.06	45
2007	Black Hills	Male	Adult	0.9	0.09	10
2008	Black Hills	Male	Adult	0.57	0.1	14
2009	Black Hills	Male	Adult	0.53	0.1	19
2011	CSP	Female	Adult	0.8	0.06	40
2013	CSP	Female	Adult	0.93	0.04	42
2011	CSP	Both	Calf	0.07	0.04	30
2012	CSP	Both	Calf	0.27	0.08	37
2012	Black Hills	Female	Adult	0.87	0.06	40
2013	Black Hills	Female	Adult	0.83	0.04	43
2012	Black Hills	Both	Calf	0.65	0.04	37
2013	Black Hills	Both	Calf	0.76	0.08	38

APPENDIX 2

Black Hills adult (>1-year-old) cow elk annual survival and cause-specific mortality rates with 95% credible intervals, 2015-2021.

Year	Survival	Harvest Rate	Other Mortality Rate	# Monitored
2015	87% (78 - 94%)	7% (2 - 13%)	6% (2 - 12%)	81
2016	76% (67 - 83%)	20% (13 - 28%)	5% (2 - 9%)	102
2017	70% (61 - 78%)	21% (14 - 30%)	9% (4 - 15%)	109
2018	82% (75 - 88%)	10% (6 - 16%)	8% (4 - 13%)	116
2019	85% (78 - 91%)	9% (5 - 14%)	6% (3 - 11%)	141
2020	86% (80 - 91%)	4% (2 - 7%)	10% (6 - 15%)	151
2021	94% (88 - 98%)	3% (1 - 8%)	3% (1 - 7%)	114

ESTIMATING ELK HARVEST AND HARVEST AGE-STRUCTURE

INTRODUCTION

Population management objectives are established across 18 antlerless elk (*Cervus elaphus*) harvest management units in South Dakota (Figure 1). The South Dakota Game, Fish and Parks (SDGFP) Commission sets biennial elk hunting license allocation and season structure, and these are used as the primary management option to meet population objective goals. Estimates of the elk population and antlerless harvest are used to inform management across 11 antlerless elk management units within the Black Hills management area. Additionally, the population projection model used to predict future population growth is based on expected changes to adult and juvenile cohorts for both sexes from harvest removal across various hunting seasons. Future model developments can leverage more-specific age-at-harvest data to improve population projection inference. In addition to population modeling benefits afforded via harvest data, elk hunter success and bull age-structure harvest objectives have been established. As a result, the SDGFP critically relies on both an understanding of age- and sex-specific harvest by season.

METHODS

Although harvest reporting of elk is mandatory, harvest of adult male, adult female, male calves, and female calves are estimated annually by surveying all elk hunters and estimating harvest based on reporting rates (SDGFP 2021). Harvest is estimated for each license type (21 = any elk; 23 = antlerless elk) and hunting unit within 5 different elk hunting seasons including: 1) Black Hills firearms elk; 2) Archery elk (Black Hills only); 3) Prairie firearms elk; 4) Custer State Park firearms elk; and 5) Custer State Park early archery elk.

Surveys were administered using email internet surveys with follow-up mail card surveys to non-respondents to obtain the number of hunting recreation days, gender and age (adult/calf) of elk harvested if successful, type of land hunted, and hunter satisfaction. Total harvest was estimated by dividing the reported harvest by the proportions of hunters that responded for each unit and respondents were assumed to be representative of the population of hunters in each unit.

More specific information about harvest age-structure is obtained using cementum annuli tooth aging techniques. The front two lower incisor teeth are collected with every elk harvest that is checked in for mandatory reporting. All usable teeth are aged to year-specific age-classes.

RESULTS

In 2021, 1,441 elk licenses were sold, and 334 cows and 508 bulls were harvested based on hunter survey data (SDGFP 2021; Appendix 1). Among Black Hills elk management units, 193 of 236 (82%) cows and 399 of 440 bulls (91%) were aged using cementum annuli tooth aging techniques (Appendix 2).

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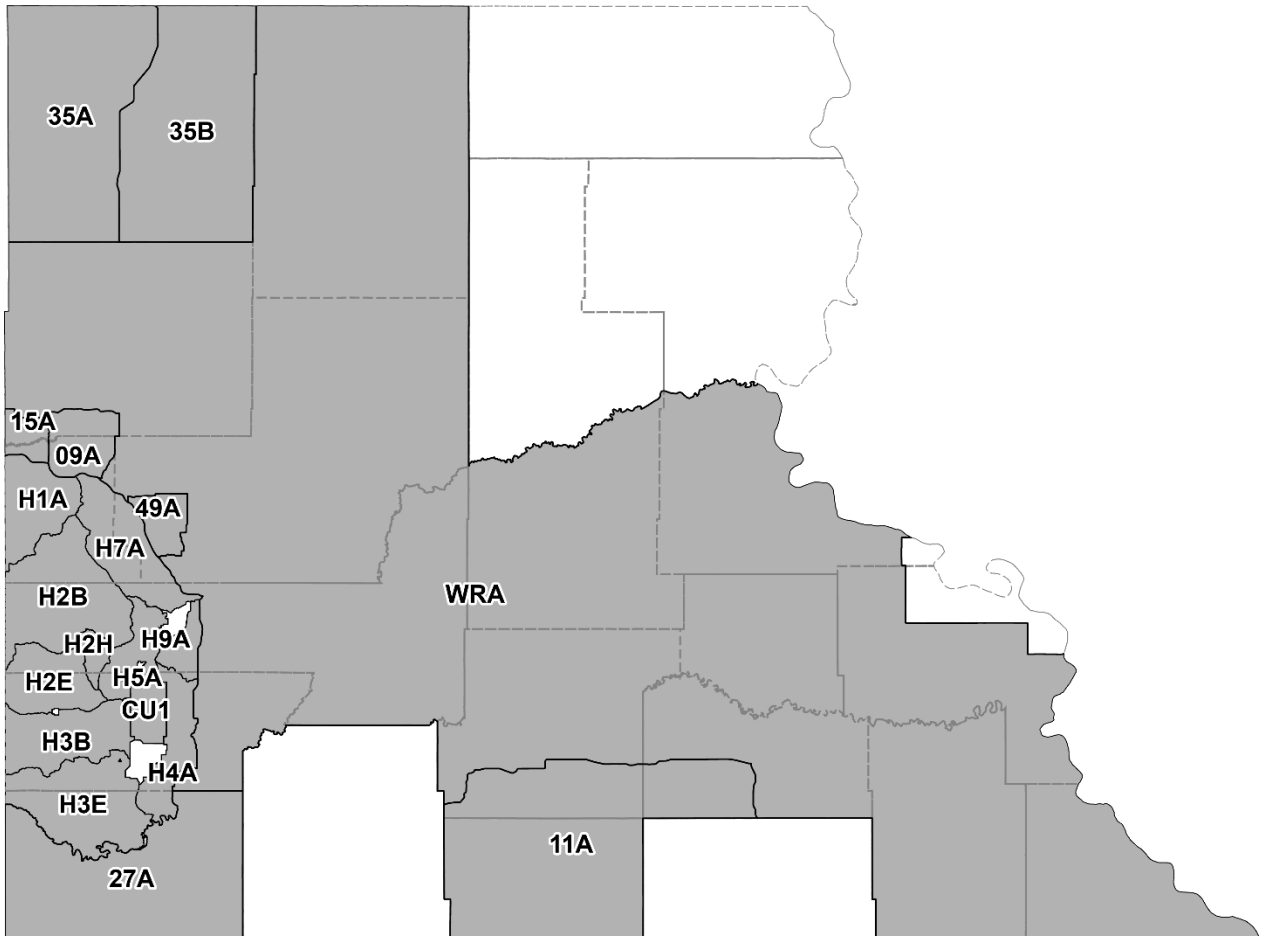

Figure 1. Antlerless elk management hunting units within the Black Hills region (unit names preceded by "H"), Custer State Park (CU1), and Prairie region.

APPENDIX 1

Elk applications, licenses sold and harvest estimates, 2017-2021 (SDGFP 2021).

Year	Weapon	Unit-Type	Applications	Sold	Bulls	Cows	Bull Calves	Cow Calves
2017	Archery	CU1-21	3,704	3	1	0	0	0
2017	Archery	H1A-21	641	25	5	0	0	0
2017	Archery	H1A-23	6	9	0	0	0	0
2017	Archery	H2A-21	3,628	88	34	1	0	0
2017	Archery	H2A-23	55	101	1	15	0	0
2017	Archery	H3A-21	380	24	10	2	0	0
2017	Archery	H3A-23	4	10	0	1	0	0
2017	Archery	H5A-21	33	2	1	0	0	0
2017	Archery	H7A-21	143	5	0	0	0	0
2017	Archery	H7A-23	2	5	0	0	0	0
2017	Firearm	09A-21	448	10	8	0	0	0
2017	Firearm	09A-23	31	40	0	5	0	1
2017	Firearm	11A-23	23	10	0	8	0	0
2017	Firearm	11B-21	512	12	12	0	0	0
2017	Firearm	11C-21	250	12	9	0	0	0
2017	Firearm	11D-23	61	20	0	13	0	1
2017	Firearm	15A-21	250	10	2	0	0	0
2017	Firearm	15A-23	13	10	0	1	0	0
2017	Firearm	27A-21	644	15	9	1	0	0
2017	Firearm	27A-23	17	10	0	3	1	0
2017	Firearm	CU1-21	8,828	9	8	0	0	0
2017	Firearm	CU1-23	2,052	10	0	8	0	1
2017	Firearm	CU2-23	982	9	1	6	0	0
2017	Firearm	CU3-23	402	10	0	9	0	0
2017	Firearm	H1A-21	1,136	75	53	6	0	0
2017	Firearm	H1B-23	57	30	0	8	0	0
2017	Firearm	H2A-21	8,825	247	196	11	1	0
2017	Firearm	H2B-23	210	173	0	94	3	5
2017	Firearm	H2C-23	41	125	0	78	5	4
2017	Firearm	H2D-23	11	25	0	11	1	3
2017	Firearm	H2E-23	93	197	0	87	3	9
2017	Firearm	H2F-23	80	198	0	108	7	8
2017	Firearm	H2G-23	22	123	0	91	4	11
2017	Firearm	H2H-23	6	15	0	9	0	0
2017	Firearm	H2I-23	3	15	0	13	0	0
2017	Firearm	H2J-23	1	15	0	8	0	2
2017	Firearm	H3A-21	1,222	80	54	8	0	0
2017	Firearm	H3B-23	15	14	0	4	0	1
2017	Firearm	H3C-23	2	15	0	9	0	0

Year	Weapon	Unit-Type	Applications	Sold	Bulls	Cows	Bull Calves	Cow Calves
2017	Firearm	H3D-23	0	15	0	11	0	0
2017	Firearm	H3E-23	19	50	0	16	1	3
2017	Firearm	H3F-23	10	50	0	23	0	5
2017	Firearm	H3G-23	4	51	0	28	1	1
2017	Firearm	H4A-21	35	8	7	0	0	0
2017	Firearm	H5A-21	52	5	3	0	0	0
2017	Firearm	H7A-21	299	20	19	0	0	0
2017	Firearm	H7B-23	13	20	0	6	0	0
2017	Firearm	H9A-21	44	5	5	0	0	0
2017	Firearm	H9B-23	1	10	0	4	1	0
2018	Archery	CU1-21	3,772	3	2	0	0	0
2018	Archery	H1A-21	660	19	5	0	0	0
2018	Archery	H1A-23	11	10	0	2	1	0
2018	Archery	H2A-21	3,671	88	47	1	1	0
2018	Archery	H2A-23	42	50	0	11	0	1
2018	Archery	H3A-21	446	25	7	0	0	0
2018	Archery	H3A-23	10	20	0	1	0	0
2018	Archery	H5A-21	40	2	0	0	0	0
2018	Archery	H7A-21	126	5	3	0	0	0
2018	Firearm	09A-21	316	10	8	0	0	0
2018	Firearm	09A-23	24	10	0	6	0	0
2018	Firearm	11A-23	41	17	0	16	0	0
2018	Firearm	11B-21	496	16	16	0	0	0
2018	Firearm	11C-21	195	16	10	1	0	0
2018	Firearm	11D-23	78	30	0	20	0	6
2018	Firearm	15A-21	155	8	8	0	0	0
2018	Firearm	15A-23	8	4	0	0	0	0
2018	Firearm	27A-21	437	10	8	0	0	0
2018	Firearm	27A-23	21	10	0	3	1	0
2018	Firearm	35A-21	1,309	8	8	0	0	0
2018	Firearm	CU1-21	8,670	9	6	0	1	0
2018	Firearm	CU1-23	1,122	10	0	3	0	0
2018	Firearm	CU2-23	519	10	0	1	0	0
2018	Firearm	CU3-23	647	1	0	0	0	0
2018	Firearm	CU4-23	363	0	0	0	0	0
2018	Firearm	CU5-23	300	0	0	0	0	0
2018	Firearm	CU6-23	224	2	0	0	0	0
2018	Firearm	H1A-21	1,131	60	42	0	1	0
2018	Firearm	H1B-23	53	20	0	7	0	0
2018	Firearm	H2A-21	8,534	249	177	12	1	1
2018	Firearm	H2B-23	206	75	0	47	3	1
2018	Firearm	H2C-23	41	75	0	36	3	5

Year	Weapon	Unit-Type	Applications	Sold	Bulls	Cows	Bull Calves	Cow Calves
2018	Firearm	H2D-23	3	25	0	10	0	2
2018	Firearm	H2E-23	98	75	0	32	0	2
2018	Firearm	H2F-23	69	75	0	44	0	8
2018	Firearm	H2G-23	27	75	0	58	0	2
2018	Firearm	H2H-23	7	15	0	2	0	0
2018	Firearm	H2I-23	1	15	0	12	0	0
2018	Firearm	H2J-23	1	15	0	11	0	1
2018	Firearm	H3A-21	1,190	80	56	3	2	0
2018	Firearm	H3B-23	18	15	0	5	0	0
2018	Firearm	H3C-23	4	15	0	4	0	0
2018	Firearm	H3D-23	2	15	0	3	0	0
2018	Firearm	H3E-23	21	50	0	23	0	3
2018	Firearm	H3F-23	6	50	0	27	2	1
2018	Firearm	H3G-23	4	50	0	21	1	2
2018	Firearm	H4A-21	54	10	9	0	0	0
2018	Firearm	H4B-23	3	10	0	7	0	0
2018	Firearm	H5A-21	58	5	3	0	0	0
2018	Firearm	H7A-21	278	10	9	0	0	0
2018	Firearm	H7B-23	8	10	0	3	0	0
2018	Firearm	H9A-21	51	10	4	0	0	0
2018	Firearm	H9B-23	3	20	0	9	1	0
2019	Archery	CU1-21	4,055	3	3	0	0	0
2019	Archery	H1A-21	705	18	15	0	0	0
2019	Archery	H1A-23	7	9	0	3	0	0
2019	Archery	H2A-21	3,831	89	44	0	1	0
2019	Archery	H2A-23	82	50	0	6	0	0
2019	Archery	H3A-21	557	25	14	0	0	0
2019	Archery	H3A-23	8	18	0	5	0	0
2019	Archery	H5A-21	28	2	1	0	0	0
2019	Archery	H7A-21	164	5	3	0	0	0
2019	Firearm	09A-21	350	10	6	0	0	0
2019	Firearm	09A-23	31	10	0	10	0	0
2019	Firearm	11A-23	39	18	0	15	0	1
2019	Firearm	11B-21	529	16	10	1	0	0
2019	Firearm	11C-21	221	15	10	0	0	0
2019	Firearm	11D-23	95	30	0	17	1	1
2019	Firearm	15A-21	131	8	0	0	0	0
2019	Firearm	15A-23	10	5	0	0	0	0
2019	Firearm	27A-21	454	10	7	0	0	0
2019	Firearm	27A-23	21	10	0	5	0	0
2019	Firearm	35A-21	1,950	8	7	0	0	0
2019	Firearm	CU1-21	8,949	9	8	0	0	0

Year	Weapon	Unit-Type	Applications	Sold	Bulls	Cows	Bull Calves	Cow Calves
2019	Firearm	H1A-21	1,194	60	42	4	0	0
2019	Firearm	H1B-23	45	20	0	6	0	0
2019	Firearm	H2A-21	8,686	248	179	14	2	2
2019	Firearm	H2B-23	227	72	0	34	2	3
2019	Firearm	H2C-23	63	74	0	23	0	0
2019	Firearm	H2D-23	10	24	0	8	0	1
2019	Firearm	H2E-23	90	75	0	32	2	6
2019	Firearm	H2F-23	74	73	0	40	3	0
2019	Firearm	H2G-23	40	73	1	50	3	4
2019	Firearm	H2H-23	7	14	0	2	0	0
2019	Firearm	H2I-23	6	15	0	9	0	0
2019	Firearm	H2J-23	4	15	0	6	1	0
2019	Firearm	H3A-21	1,401	78	61	1	1	0
2019	Firearm	H3B-23	18	15	0	9	0	1
2019	Firearm	H3C-23	3	15	0	8	1	0
2019	Firearm	H3D-23	3	15	0	8	0	0
2019	Firearm	H3E-23	18	49	0	19	2	0
2019	Firearm	H3F-23	20	50	0	21	0	1
2019	Firearm	H3G-23	8	49	0	15	0	1
2019	Firearm	H4A-21	65	10	9	1	0	0
2019	Firearm	H4B-23	3	10	0	4	0	0
2019	Firearm	H5A-21	65	4	3	0	0	0
2019	Firearm	H7A-21	271	10	9	1	0	0
2019	Firearm	H7B-23	15	10	0	9	0	0
2019	Firearm	H9A-21	57	10	10	0	0	0
2019	Firearm	H9B-23	3	20	0	11	0	1
2020	Archery	CU1-21	4,353	3	1	0	0	0
2020	Archery	H1A-21	756	17	10	1	0	0
2020	Archery	H1A-23	20	8	0	2	0	0
2020	Archery	H2A-21	4,081	80	49	1	1	0
2020	Archery	H2A-23	78	37	0	2	0	0
2020	Archery	H3A-21	687	32	17	1	0	0
2020	Archery	H3A-23	17	19	0	4	0	0
2020	Archery	H5A-21	57	2	1	0	0	0
2020	Archery	H7A-21	188	9	3	0	0	0
2020	Firearm	09A-21	335	10	6	0	0	0
2020	Firearm	09A-23	42	15	0	1	0	0
2020	Firearm	11A-23	34	16	0	8	0	2
2020	Firearm	11B-21	451	16	11	0	0	0
2020	Firearm	11C-21	155	16	12	1	1	0
2020	Firearm	11D-23	60	30	0	22	1	4
2020	Firearm	11E-23	44	30	0	11	1	1

Year	Weapon	Unit-Type	Applications	Sold	Bulls	Cows	Bull Calves	Cow Calves
2020	Firearm	11F-23	9	30	0	14	0	2
2020	Firearm	15A-21	115	8	1	1	0	0
2020	Firearm	15B-23	7	5	0	0	0	0
2020	Firearm	27A-21	515	9	8	0	0	0
2020	Firearm	27A-23	31	9	0	6	0	0
2020	Firearm	35A-21	729	4	4	0	0	0
2020	Firearm	35A-23	31	7	0	4	0	0
2020	Firearm	35B-21	1,214	4	4	0	0	0
2020	Firearm	35B-23	68	12	0	6	2	0
2020	Firearm	CU1-21	9,385	9	8	0	0	0
2020	Firearm	H1A-21	1,293	49	39	1	0	0
2020	Firearm	H1B-23	56	15	0	9	0	1
2020	Firearm	H2A-21	9,006	237	197	9	0	0
2020	Firearm	H2B-23	258	22	0	14	0	1
2020	Firearm	H2E-23	248	49	0	20	0	1
2020	Firearm	H2H-23	4	5	0	3	0	0
2020	Firearm	H2I-23	9	15	0	1	0	0
2020	Firearm	H2J-23	5	15	0	7	0	0
2020	Firearm	H3A-21	1,645	99	74	4	0	1
2020	Firearm	H3B-23	31	29	0	9	1	0
2020	Firearm	H3C-23	8	30	0	8	0	0
2020	Firearm	H3D-23	6	29	0	9	0	0
2020	Firearm	H3E-23	29	58	0	20	0	6
2020	Firearm	H3F-23	14	59	1	21	0	1
2020	Firearm	H3G-23	1	60	0	16	2	1
2020	Firearm	H4A-21	76	20	20	0	0	0
2020	Firearm	H4B-23	11	40	0	21	1	3
2020	Firearm	H5A-21	74	5	3	1	0	0
2020	Firearm	H7A-21	334	20	10	5	0	0
2020	Firearm	H7B-23	25	15	0	7	0	3
2020	Firearm	H9A-21	63	15	11	0	0	2
2020	Firearm	H9B-23	2	40	0	19	0	1
2020	Firearm	WRA-21	652	10	5	0	0	0
2020	Firearm	WRA-23	40	20	0	3	0	0
2021	Archery	CU1-21	4,456	3	1	0	0	0
2021	Archery	H1A-21	754	20	9	0	0	0
2021	Archery	H1A-23	5	10	0	3	0	0
2021	Archery	H2A-21	4,067	81	49	2	0	0
2021	Archery	H2A-23	75	40	0	7	0	0
2021	Archery	H3A-21	756	36	18	1	0	0
2021	Archery	H3A-23	22	20	0	1	0	0
2021	Archery	H5A-21	39	2	0	0	0	0

Year	Weapon	Unit-Type	Applications	Sold	Bulls	Cows	Bull Calves	Cow Calves
2021	Archery	H7A-21	248	10	6	0	0	0
2021	Firearm	CU1-21	9,215	8	8	0	0	0
2021	Firearm	H1A-21	1,317	49	32	7	0	0
2021	Firearm	H1B-23	40	15	0	9	1	3
2021	Firearm	H2A-21	8,500	241	202	6	2	0
2021	Firearm	H2B-23	194	25	0	20	0	0
2021	Firearm	H2E-23	194	50	0	38	3	1
2021	Firearm	H2H-23	2	9	0	5	0	0
2021	Firearm	H2I-23	6	15	0	3	2	0
2021	Firearm	H2J-23	1	14	0	4	0	0
2021	Firearm	H3A-21	1,727	100	78	3	0	0
2021	Firearm	H3B-23	45	30	0	14	0	2
2021	Firearm	H3C-23	9	29	0	8	0	0
2021	Firearm	H3D-23	11	35	0	18	2	2
2021	Firearm	H3E-23	25	59	0	20	0	2
2021	Firearm	H3F-23	8	60	0	19	0	1
2021	Firearm	H3G-23	4	60	0	23	0	3
2021	Firearm	H4A-21	83	20	15	0	0	0
2021	Firearm	H4B-23	8	44	0	9	1	1
2021	Firearm	H5A-21	67	5	3	0	0	0
2021	Firearm	H7A-21	343	20	16	1	0	1
2021	Firearm	H7B-23	16	15	0	7	0	0
2021	Firearm	H9A-21	53	14	10	1	0	0
2021	Firearm	H9B-23	3	45	0	16	3	3
2021	Firearm	09A-21	304	10	3	0	0	0
2021	Firearm	09A-23	20	15	0	8	0	0
2021	Firearm	11A-23	41	18	0	9	0	0
2021	Firearm	11B-21	450	16	13	0	0	0
2021	Firearm	11C-21	181	16	9	1	0	0
2021	Firearm	11D-23	75	31	1	19	0	4
2021	Firearm	11E-23	45	30	0	0	2	0
2021	Firearm	11F-23	23	30	0	0	0	0
2021	Firearm	15A-21	104	8	2	0	0	0
2021	Firearm	15A-23	5	5	0	0	0	0
2021	Firearm	27A-21	533	10	9	0	0	0
2021	Firearm	27A-23	26	10	0	8	0	0
2021	Firearm	35A-21	754	4	4	0	0	0
2021	Firearm	35A-23	24	8	0	6	1	0
2021	Firearm	35B-21	1,333	4	4	0	0	0
2021	Firearm	35B-23	69	12	0	8	0	0
2021	Firearm	WRA-21	881	10	8	0	0	0
2021	Firearm	WRA-23	44	20	0	6	0	0

APPENDIX 2

Number of harvested elk aged by year-class from Black Hills, CSP and Prairie regions, 2017-2021.

		Black Hills		CSP		Prairie	
YEAR	AGE	BULLS	COWS	BULLS	COWS	BULLS	COWS
2017	0.5	8	53	0	1	2	2
2017	1.5	15	68	0	2	1	2
2017	2.5	105	94	0	3	8	6
2017	3.5	118	83	4	2	10	5
2017	4.5	75	86	1	4	4	4
2017	5.5	22	49	3	2	2	0
2017	6.5	10	38	1	1	0	3
2017	7.5	3	33	0	1	0	1
2017	8.5	0	32	0	2	0	0
2017	9.5	2	21	0	1	0	0
2017	10.5	1	96	0	5	1	0
2017	11.5	0	4	0	2	0	0
2017	12.5	0	1	0	0	0	0
2017	18.5	0	1	0	0	0	0
2018	0.5	12	24	0	0	2	6
2018	1.5	14	43	0	0	0	5
2018	2.5	19	42	1	1	0	6
2018	3.5	62	51	1	1	9	4
2018	4.5	88	32	2	0	18	2
2018	5.5	79	39	3	0	6	3
2018	6.5	31	22	2	0	3	4
2018	7.5	14	18	0	0	0	2
2018	8.5	6	10	0	0	0	1
2018	9.5	3	15	0	0	1	2
2018	10.5	0	13	0	0	0	1
2018	11.5	0	9	0	0	0	0
2018	12.5	0	8	0	0	0	0
2018	13.5	0	9	0	0	0	0
2018	14.5	1	8	0	0	0	0
2018	15.5	0	2	0	0	1	0
2018	16.5	0	2	0	0	0	0
2018	17.5	0	1	0	1	0	0
2018	19.5	0	1	0	0	0	0
2019	0.5	10	19	0	0	2	6
2019	1.5	11	22	0	0	1	2
2019	2.5	27	30	0	0	2	2
2019	3.5	53	57	0	0	2	7
2019	4.5	97	46	2	0	13	1
2019	5.5	81	34	4	0	5	6
2019	6.5	46	15	4	0	4	1
2019	7.5	31	13	0	0	4	2
2019	8.5	7	22	0	0	0	3
2019	9.5	4	10	0	0	3	1

		Black Hills		CSP		Prairie	
YEAR	AGE	BULLS	COWS	BULLS	COWS	BULLS	COWS
2019	10.5	0	16	1	0	0	1
2019	11.5	0	8	0	0	0	1
2019	12.5	0	6	0	0	0	1
2019	13.5	0	5	0	0	0	0
2019	14.5	0	5	0	0	0	0
2019	15.5	1	3	0	0	0	0
2019	16.5	0	2	0	0	0	0
2019	21.5	0	1	0	0	0	0
2020	0.5	3	22	0	0	10	8
2020	1.5	10	19	0	0	0	14
2020	2.5	18	15	0	0	3	6
2020	3.5	50	20	1	0	2	6
2020	4.5	99	29	5	0	9	5
2020	5.5	102	25	1	0	7	8
2020	6.5	69	17	2	0	6	2
2020	7.5	32	8	0	0	5	2
2020	8.5	10	7	0	0	1	1
2020	9.5	5	9	0	0	0	2
2020	10.5	0	8	0	0	1	1
2020	11.5	1	4	0	0	0	0
2020	12.5	0	3	0	0	0	0
2020	13.5	0	2	0	0	0	1
2020	14.5	0	1	0	0	0	1
2020	15.5	0	1	0	0	0	0
2020	16.5	0	1	0	0	0	0
2020	18.5	0	1	0	0	0	0
2020	21.5	0	1	0	0	0	0
2021	0.5	6	15	0	0	1	8
2021	1.5	17	19	0	0	2	9
2021	2.5	17	23	0	0	4	0
2021	3.5	41	24	0	0	4	0
2021	4.5	96	27	0	0	12	0
2021	5.5	92	32	5	0	8	0
2021	6.5	66	18	3	0	3	0
2021	7.5	45	13	0	0	3	0
2021	8.5	14	7	0	0	4	0
2021	9.5	7	11	0	0	1	0
2021	10.5	1	7	0	0	0	0
2021	11.5	1	3	0	0	0	0
2021	12.5	1	3	0	0	0	0
2021	13.5	0	3	1	0	0	0
2021	14.5	0	2	0	0	0	0
2021	15.5	0	1	0	0	0	0
2021	18.5	0	1	0	0	0	0
2021	19.5	0	1	0	0	0	0
2021	22.5	0	1	0	0	0	0

ESTIMATING OVERWINTER ELK POPULATION

INTRODUCTION

An overwinter elk (*Cervus elaphus*) population goal of 6,000-8,000 (2.1-2.8 elk per square mile) has been established across the Black Hills and 500-600 (4.4-5.3 elk per square mile) in Custer State Park (SDGFP 2021). Biennial elk hunting license allocation and season structure for 11 antlerless elk management units in the Black Hills are used to manage the elk population towards the population goal. An estimate of the overwinter elk population is required to provide an understanding of where the population is at relative to goal, and how the population changes as a function of hunting season regulations. Late-winter aerial helicopter surveys are conducted every 4 years to provide a winter population estimate. For years when no observation surveys are conducted, the overwinter estimate is projected to subsequent years using herd composition, survival and harvest data.

METHODS

Since the 1940s, aerial surveys have been used to evaluate the elk population in the Black Hills of South Dakota. Sampling design and methodology used to estimate the population from the observation data has evolved over the years. The current sightability model used to estimate abundance from observation surveys is described below in the model structure section.

Observation data for overwinter helicopter surveys are collected every 4 years by systematically flying across all Black Hills hunting units using 2 observers and 1 pilot in an R-44 helicopter at speeds of 40-50 mph and 100-150 ft above ground. Transects spaced 650-1,000 ft apart are flown within each of the 252 subunits spanning the Black Hills (Figure 1). Once an elk group is sighted, the search pattern is interrupted to collect information for visual obstruction, group size, and snow cover covariates (Unsworth et al. 1999, Jarding 2010, Phillips 2011). In addition, GPS location is recorded, and photos are taken to confirm group sizes for groups that exceeded 50 animals.

Model Structure

During the most recent survey in 2020, parameter estimates for the sightability model from Phillips (2011) were updated using an additional year of data to better represent the range of conditions expected to occur during the helicopter surveys. From 2009 to 2012, 176 elk groups (*i*), with at least one radiocollared elk, were used to model the logit of detection probability (*p*) as a linear function of visual obstruction, group size, and snow cover.

$$logit(\rho_i) = 0.1446 + 0.1001 \times grp\ size_i - 0.0361 \times \%\ visual\ obs_i + 0.0158 \times \%\ snow\ cover_i$$

The associated variance-covariance matrix used was:

$$\begin{bmatrix} 0.367666626 & -0.000028222 & -0.000277824 & -0.000020961 \\ -0.000027934 & 0.000000015 & -0.000000018 & -0.000000001 \\ -0.000274996 & -0.000000018 & 0.000000793 & 0.000000021 \\ -0.000029857 & -0.000000001 & 0.000000020 & 0.000000002 \end{bmatrix}$$

Total population, variance and confidence intervals (Wong 1996) from observation data were estimated from the logistic model using the SightabilityModel package (Fieberg 2012) in Program R.

RESULTS

Aerial surveys of elk populations in the Black Hills were last conducted from February 6 to March 1, 2020 using three R-44 helicopters. A total of 183 survey hours were flown across 2,954 square miles in South Dakota and an additional 30 hours were flown across 596 square miles on the Wyoming side of the Black Hills in suspected elk winter range. Adjacent subunits were flown with minimal time delays to minimize elk movements between subunits and the potential of elk herds being missed completely or double sampled. A total of 5,834 elk were counted in the South Dakota Black Hills hunting units excluding Custer State Park and Wind Cave National Park (Appendix 1). The sightability model estimate was 6,483 elk (95% CI: 6,098 – 7,958; 2.3 elk per square mile). Within CSP, 435 elk were counted, and the model adjusted estimate was 457 elk (95% CI: 442 – 544; 4.0 elk per square mile). Crews counted 1,519 elk in Wyoming with a model adjusted estimate of 1,687 elk (95% CI: 1,584 – 2,118).

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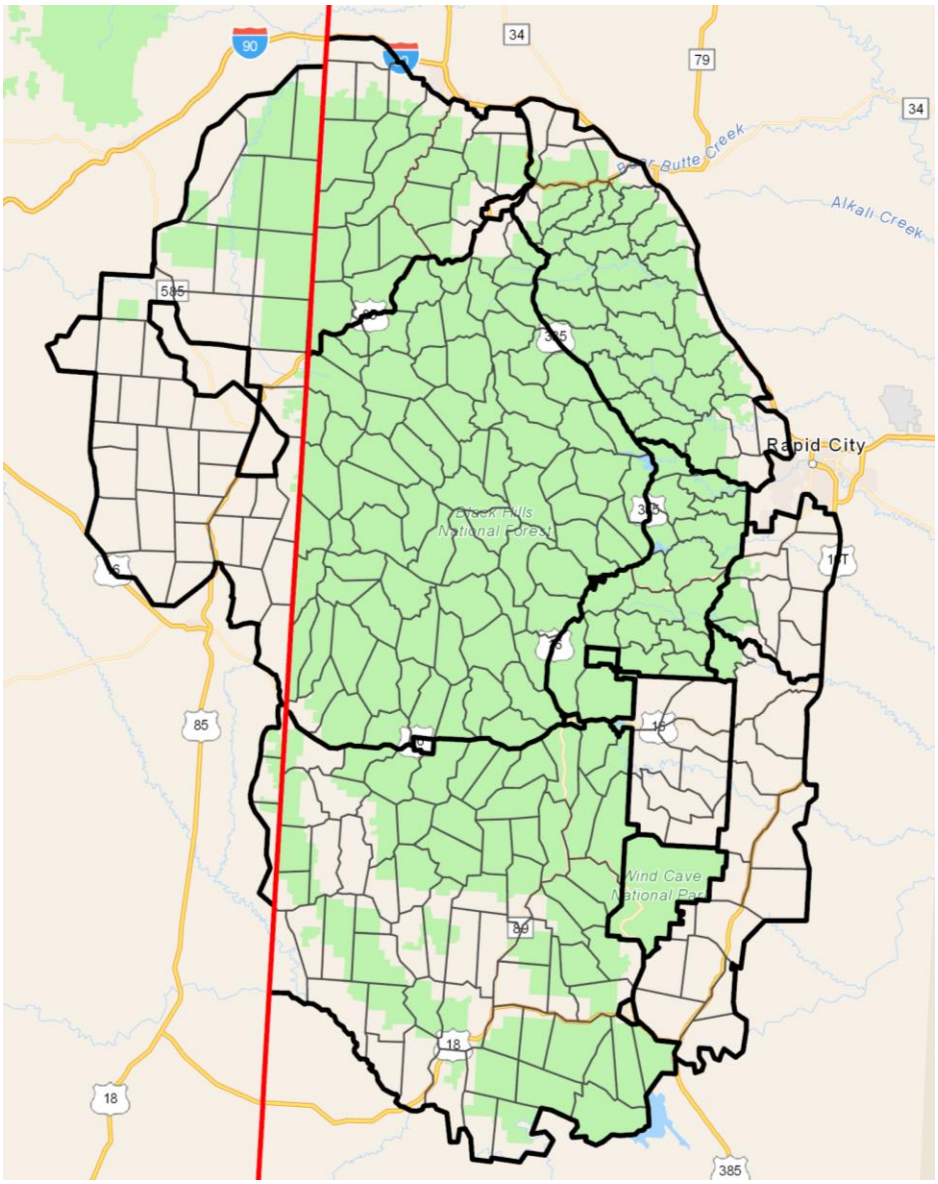

Figure 1. Two-hundred ninety-four subunits (thin gray lines) spanning 3,595 square miles where elk were systematically surveyed with helicopters in February and March 2020. South Dakota any elk (license type 23) hunting units and Wyoming survey outside boundaries are indicated with thick black lines and the Wyoming-South Dakota state boundary is indicated with a thick red line.

APPENDIX 1

Aerial survey results and population estimates with 95% confidence intervals in parenthesis from Black Hills (SD and WY), Custer State Park (CSP), and Wind Cave National Park, 2013-2020.

Year	Area	Observed	Detection Probability	Population Estimate
2013	Black Hills (SD)	4,624	0.91	5,077 (4,807 - 6,116)
2013	CSP	501	0.99	506 (502 - 594)
2016	Black Hills (SD)	6,356	0.88	7,185 (6,692 - 9,068)
2016	CSP	378	0.83	455 (404 - 733)
2016	Black Hills (WY)	923	0.85	1,091 (988 - 1,521)
2016	Wind Cave NP	484	0.69	699 (566 - 1,268)
2020	Black Hills (SD)	5,834	0.9	6,483 (6,098 - 7,958)
2020	CSP	435	0.95	457 (442 - 544)
2020	Black Hills (WY)	1,519	0.9	1,687 (1,584 - 2,118)

ELK POPULATION PROJECTION MODEL

INTRODUCTION

An overwinter elk (*Cervus elaphus*) population goal of 6,000-8,000 (2.1-2.8 elk per square mile) has been established across the Black Hills and 500-600 (4.4-5.3 elk per square mile) in Custer State Park (SDGFP 2021). Population projection models are used to annually estimate abundance when aerial observation survey estimates are not available, and project future elk populations and growth rates (λ) in the Black Hills of South Dakota. Changes in hunting license allocation and season structure across 11 antlerless elk hunting units in the Black Hills are biennially set that align population growth rate objectives with estimated λ from the projection model. The projection model relies on data collected from quadrennial aerial observation, annual herd composition, camera, and harvest surveys, and intermittent survival monitoring research projects. The model projections provide objective information for understanding how various hunting season structures may affect population growth. Parameter estimates for models are based on averages from available data, and error associated with parameters may result in error of population growth estimates.

METHODS

The two age-class sex-specific projection model has two stages within each year, the first represents new elk added to the fall population when calves are born and survive to the beginning of the hunting season, and the second stage removes elk that die each year from September 1 to August 31. Elk deaths are related to multiple causes, the majority include harvest, wounding loss, predation, vehicle accidents, starvation, and disease. The population projection is repeated across multiple years to evaluate changes in elk abundance as a function of potential hunting season changes (Figure 1).

The model is initiated with an estimate of fall adult elk in the Black Hills by multiplying the late winter helicopter survey population estimate by adult survival from March to September 1. Pre-fall recruitment adult populations are estimated for each hunting unit (Figure 2) using previous harvest proportions and trail camera survey data. Adult (>1 year old) bull and cow cohorts are estimated by multiplying the fall population by 3-year averages from herd composition surveys. As an example, adult bulls are estimated by multiplying the fall adult population by the proportion of adult bulls (i.e., antlered elk) observed among all adult elk from fall herd composition counts.

Once the model has been initiated the first year with the number of adult males and adult females in the fall, the 1st of 2 stages that are repeated annually proceeds. New calves are recruited into the fall population by multiplying fall adult cows by the proportion of calves observed among calves and females from herd composition surveys. This completes the first stage of the projection model, accounting for fall calf recruitment (Figure 1).

The 2nd stage removes all deaths that are expected to occur annually from September 1 to August 31. Average annual non-harvest mortality estimates for adult bulls, adult cows and calves (~3 to 14 months old), based on known fate data from radiocollared elk in the Black Hills, are used to remove deaths not related to harvest. Total harvest related mortality is removed by subtracting cohort-specific estimates. Total harvest mortality is estimated by inflating harvest, estimated from hunter surveys, by 15% to account for wounding loss. Because changes to hunting licenses are used to increase or decrease annual mortality rates of antlered and antlerless elk, the model adjusts estimated harvest based on increases or decreases to antlered and antlerless licenses when projecting the population to future years. Assuming additive harvest mortality, changes in license type allocations from the previous year are multiplied by 5-year average license type success rates to predict future harvest. Calves remaining at the end of the year are aged into the adult cohort, assuming a 50:50 sex ratio. In addition, a parameter is used to model net emigration via permanent dispersal of yearling bulls. This completes the annual cycle resulting in a pre-recruitment population. The process is repeated for subsequent years as illustrated in figure 1. Population parameters were optimized by comparing projections between winter aerial survey estimates in 2013, 2016 and 2020.

Data from aerial surveys in 2020 resulted in an estimate of 6,483 elk wintering in the Black Hills. A 3-year average of 25 adult bulls:100 adult cows from 2019-2021 fall herd composition data was used to estimate adult bulls and adult cows after multiplying the 2020 aerial survey estimate by adult survival from March 1 to September 1 (98%). Calves were recruited into the fall population by multiplying the adult cows by the 2019-2021 average of 45 calves:100 adult cows. Annual (Sep. 1 to Aug. 31) calf non-hunting mortality (27%), adult female non-hunting mortality (7%), and adult bull non-hunting mortality (15%) was used to project each population cohort to the next year.

A different projection model is used in CSP to estimate abundance and rate of change during years when aerial estimates are not available. Data from aerial surveys in 2020 resulted in an estimate of 457 elk wintering in CSP. The aerial survey estimate is used to project the population through time using a Lefkovitch matrix model. The matrix model is a post-breeding model which includes male and female calves, male and female yearlings, 2+ year old males, 2-7 year-old females, and 8+ year-old females. Survival rates, pregnancy rates, and fecundity were used to estimate future abundance. Confidence intervals for annual abundance estimates are developed using Monte Carlo simulation methods, which fully accounts for uncertainty in all input variables. To predict how different tag recommendations may impact growth rates, change in harvest is assumed to be additive, and various harvest simulations are conducted to ensure CSP is maintaining the elk population objective.

RESULTS

From the winter aerial survey estimate of 6,483 elk in the Black Hills management units, a 9% population increase was projected from 2020 to 2022. Based on 2022 and 2023 hunting season licenses, the population is expected to grow another 2% from 2022 to 2024. Recommended license changes and 2-year estimated growth rates by hunting unit from 2022 to 2024 are illustrated in Figure 2. Model

projections are based on average conditions and subject to error associated with bias or sampling and process variance of input parameters.

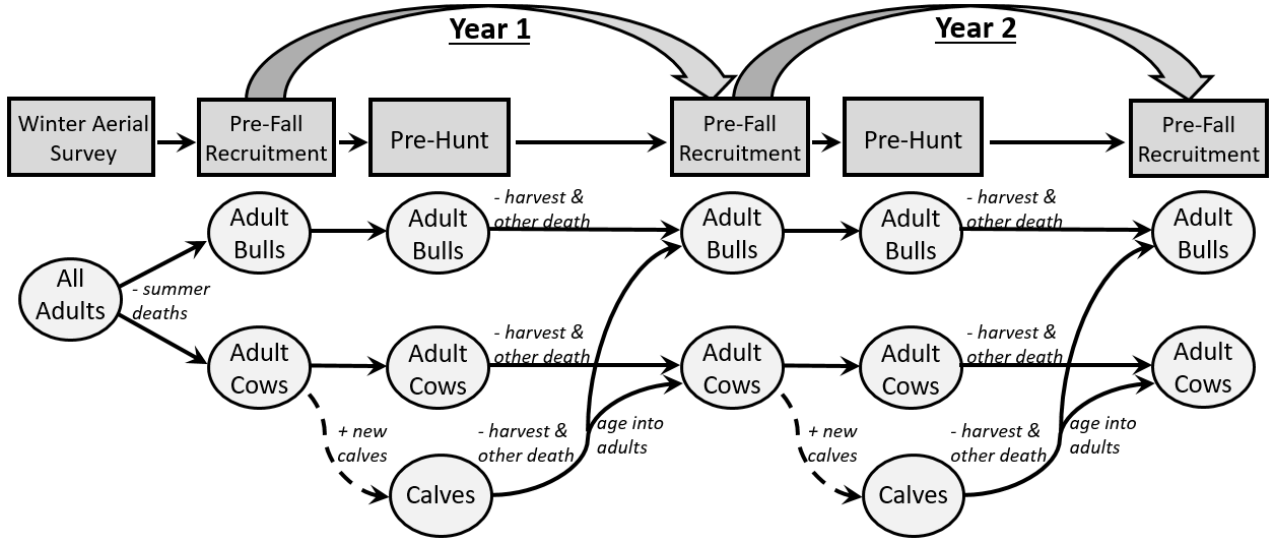

Figure 1. Graphical illustration of the elk population projection model used to predict population growth rates as a function of varying hunting season recommendations.

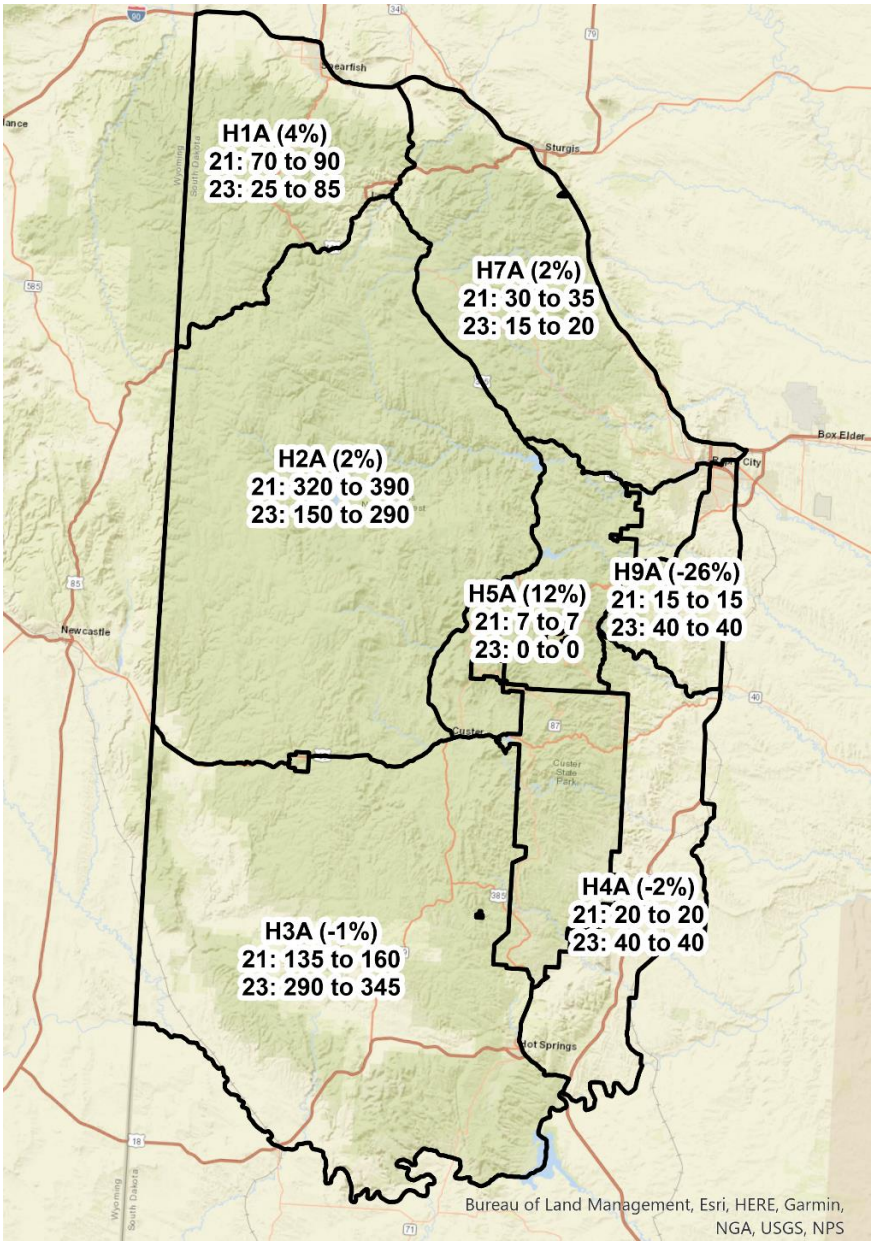

Figure 2. Projected growth rates for elk populations from 2022 to 2024 in parenthesis with changes to annual any elk (21; 2nd row) and antlerless only (23; 3rd row) licenses from 2020 and 2021 to 2022 and 2023. License changes are made biennially.